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Service life of the dwelling stock in Spain

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Abstract
Purpose Service life of buildings is an essential parameter to evaluate its operational impact in life cycle assessment (LCA). Although most studies assume building service life about 75 to 100 years since no reliable data are available, its accurate quantification is still an unresolved work. To avoid wrong generalizations, the determination of the service life of buildings according to the characteristics of every region is required.
Methods Life table, a methodology traditionally used in demographic studies, has been used in this paper to estimate the service life of buildings. This methodology has been applied to the dwelling stock of Spain for each of its 19 regions. Data acquisition and sources have been pointed out. The building obsolescence has been considered in the moment that they are in a ruinous state.
Results and discussion Life table of buildings showed that the average service life of a residential building constructed in 2001 in Spain was expected to be 80 years. Significant different results of service life among regions were found, from 54 years for a building in Ceuta to 95 years in La Rioja. It also showed that 50 % of total Spanish dwellings are younger than 30 years, and they are expected to reach the ruinous state in 2063 to 2081.
Conclusions Life table applied to buildings allows determining their service life. Its quantification is based on the buildings census, given by official institutions. Building census has to consider the year of construction and the state of conservation of the building to be applied in buildings' life table. Building service life can be used in LCA, renovation and deconstruction of the building stock, and future construction and demolition debris management.

Keywords Building obsolescence · Dwelling stock · Life cycle assessment · Life table · Service life · Operational phase

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1 Introduction

Service life of a product is essential to determine the period of its operational phase in life cycle assessment (LCA). Service life of buildings is a parameter required in the LCA of buildings and, by extension, of its materials. Environmental Product Declarations for building components can be obtained from LCA (Benveniste et al. 2011). Despite its relevance in LCA performance, little reliable data on the service life of buildings and its components are presently available. Therefore, authors are forced to make assumptions based on literature, but not on actual data (Blengini and Di Carlo 2010). Estimations of buildings service life in LCA are usually within ranges of 50, 75, or 100 years (de Gracia et al. 2010). Most studies assume a lifespan of 75–80 years (Kellenberger and Althaus 2009). Remarkably, there is still no data available nor literature about what is the service life of today's building stock in the world. To avoid wrong generalizations, the quantification of the service life of the building stock for each specific region is required.

This paper pretends to fulfill the gap on the quantification of the building service life for the operational phase of LCA, with real data and avoiding wrong estimations. This quantification is done for Spain. The aim of this paper is to present a methodology to estimate the service life of the building stock and the sources of data available for its accounting. The hypothesis to test is that the service life of the building stock can be accounted by means of the life

table, analogous to population life expectancy, and using the data given by the official statistical institutions. The life table has been applied previously to the building stock of New Zealand by Johnstone (2001), but still it is not being implemented to the estimation of the service life of the building stock probably due to the lack of proper data, which are basic to achieve good quality results. This paper presents the keys in the data acquisition in order to perform the life table of the building stock and to allow its implementation in any region's building stock. As a case study, in this paper, the service life of the dwelling stock in Spain and its regions has been estimated. This paper is focused on dwellings because of its importance in the total building stock. The regional scale of analysis is used to test the importance of relating the building service life to the inherent characteristics of the region.

2 The service life concept

The service life of a building is defined as the "period of time after installation during which a building or its part meet or exceed performance requirements" (ISO 2011). According to this definition, the service life can be used to determine the duration of the usage phase of a building (Thomsen and van der Flier 2011). Thus, service life is inherently linked with obsolescence of building stocks, which is defined by Thomsen and van der Flier (2011) as a process of declining performance resulting in the end of the service life. Bradley and Kohler (2007) found that the effective life time of building stocks is much higher than their age, and possibly independent of it, and stated that the end of the service life can be the end of the physical life, but can also be just the indication of the expected time horizon. The causes of the end of the service life of the building stock can be divided in physical and economical. From an economical point of view, the building end of life is reached at the moment when the building is depreciated (Baum 1991). Since the physical causes can be mitigated by maintenance and reinvestment with renovation and restoration of the building, the economical causes take more relevance in determining the building end of life. Marteinsson (2005) found that the subjective perception of a building was identified as the main cause in 44 % of renovations. Only 17 % of repair projects were initiated due to deterioration. Change in use and change in economic circumstances meant 26 and 13 % of renovations, respectively.

The importance of the service life of the building stock lays in its usefulness in a wide range of analysis related to buildings and its components, such as LCA, material flow analysis, materials and waste management, and the cradle to cradle concept (McDonough and Braungart 2008). Service life has an especial interest in LCA because it quantifies the duration of the operational phase. As it happens with other sectors, such as electric and electronic components (Muñoz et al. 2008), the operational phase of buildings is identified as potentially the most important life cycle stage because of its high environmental impact.

Building service life results can be addressed to the European Committee for Standardization. CEN/TC 350 "Sustainability of construction works" is developing standardized methods for the assessment of the sustainability aspects of new and existing construction works and standards for the environmental product declaration of construction products (CEN 2012). One of the working groups, CEN/TC WG2: Building life cycle description, carried out the European Standard EN 15978:2011 (EN 2011), which specifies the calculation method, based on LCA and other quantified environmental information, to assess the environmental performance of a building.

Service life can be applied to building materials, urban and territory planners, or even to the building stock economic analyses and its future evolution for dwelling policies. Service life is an important parameter for the dwelling stock design and management. Minimizing obsolescence and extending longevity are fundamental issues to maintain the physical, economic, and societal investments involved (Thomsen and van der Flier 2011). Due to the significant affectation of the building stock in the environment, prolonging its useful service life is essential to reduce the natural resources consumption and the generation of wastes (Rincón 2011).

In refurbishment, longevity of the building elements is a key factor. Service life prediction of building products is useful to forecast future expenditures related to renovation. Zavadskas et al. (2004) presented the longevity as one of the parameters considered in the multiple criteria analysis of thermal renovation of walls. The existing building stock requires continuous investments for repair and renovations, which increases life cycle impacts (Hovde and Moser 2004). Kliukas and Kudzys (2004) analyzed the probabilistic durability prediction of building elements to avoid their unfounded and premature repairing and thus to prolong their residual service life. Aktas and Bilec (2012a) determined the impact of lifetime on residential building LCA results, including the impact of interior renovation products over the lifetime of a residential building. They highlighted that choosing an arbitrary lifetime for buildings and interior finishes or excluding interior renovation impacts introduces a noteworthy amount of error into residential building LCA. Aktas and Bilec (2012b) described a hypothesis test conducted to verify the relationship between calculated service life and the probability of renovation. They found that there is a strong relationship between product service life and the

probability of renovation distributions calculated. Service life prediction of products should be differentiated according to the type of building because they have different occupant demands and renovation cycles. Anderson and Brandt (1999) considered that residential buildings have a renovation cycle of 20–50 years, offices 10–20 years, and department stores 5–10 years.

3 Methodology to estimate the building service life

3.1 Development of the life table

The methodology used in this paper to calculate the service life of a building is the life table. The life table describes the process of extinction of a generation until the disappearing of the last component, based on the experience observed along the period (Johnstone 2001). A life table is traditionally used to estimate the life expectancy of the population of a country in demographic analyses or population projections. Similarly, it can be used to calculate the service life expectancy of the building stock of a region. Gleeson (1981) and Johnstone (2001) investigated life tables to estimate the housing mortality of USA and New Zealand, respectively.

The equations used to calculate the life table are explained as follows. Buildings are considered as living individuals (P_x) and demolitions as deaths (D_x). The period where the building was built is accounted as births, and it is used as the age interval (x) (for example buildings constructed from 1950 to 1960) and the interval range (n) (in the previous example n=10, years and the range average ${}_na_x$=5 years).

The age-specific loss rate (${}_nM_x$) is defined by the number of demolished buildings per number of surviving buildings in the age interval (Eq. 1). It indicates the rate of buildings that have reached the end of its life span in the age interval.

$$ {}_nM_x = \frac{D_x}{P_x} \tag{1} $$

The probability of loss (${}_nq_x$) is defined in Eq. (2), and it considers the age-specific loss rate, the age interval, the range, and the range average. It indicates the probability rate of a building of that interval to reach the end of its life span. The probability of loss in the oldest interval is always considered 100 %, so the rate is assumed to be 1.

$$ {}_nq_x = \frac{n \cdot {}_nM_x}{1 + (n - {}_na_x) \cdot {}_nM_x} \tag{2} $$

The probability of survival (${}_nP_x$) is the inverse rate of the loss probability (Eq. (3)). It indicates the probability rate of a building of that interval to survive. The probability of surviving in the oldest interval is always considered 0 %; therefore, the rate is assumed to be 0.

$$ {}_np_x = 1 - {}_nq_x \tag{3} $$

The surviving stock at the start of an interval (${}_nl_x$) is defined in Eq. (4), and it considers the probability to survive and the building surviving stock at the start of the interval. The first interval, where the age of the building is between 0 and the first range, is considered with a ratio of 100 %, so the number of buildings is 100,000 because these calculations are over a theoretical sample of 100,000 buildings.

$$ {}_nl_{x+n} = {}_nl_x \cdot {}_np_x \tag{4} $$

The stock losses over an age interval (${}_nd_x$) are defined in Eq. (5) and they relate the surviving building stock with the probability of a building to survive in the interval. They

Table 1 State of conservation of the building according to the year of construction; surviving and deaths of the building stock for that period. Spain (units: number of buildings) (INE 2007)

Year of construction	Total	State of the building				Buildings	
		Good	Defective	Bad	Ruinous	Surviving (P_x)	Deaths (D_x)
1991–2001	1,417,202	1,379,187	30,815	6,428	772	1,416,430	772
1981–1990	1,360,191	1,331,255	21,756	3,154	4,026	1,356,165	4,026
1971–1980	1,504,984	1,427,429	60,613	9,697	7,245	1,497,739	7,245
1961–1970	1,090,319	990,104	79,627	13,912	6,676	1,083,643	6,676
1951–1960	886,544	760,049	98,115	19,372	9,008	877,536	9,008
1941–1950	539,425	433,940	77,141	19,621	8,723	530,702	8,723
1921–1940	497,039	385,972	78,438	22,063	10,566	486,473	10,566
1900–1920	426,872	312,283	77,188	24,722	12,679	414,193	12,679
<1900	901,299	653,245	157,943	55,012	35,099	866,200	35,099
Total	8,623,875	7,673,464	681,636	173,981	94,794	8,529,081	94,794

account the number of buildings that have reached the end of their life span within the interval of analysis.

$$_{n}d_{x} = {}_{n}l_{x} \cdot {}_{n}q_{x} \tag{5}$$

The stock in age interval ($_{n}l_{x}$) is defined in Eq. (6). It considers the surviving stock at the start of the interval, the stock losses over the interval, the range, and the range average. It indicates the total number of years of all buildings lived in the interval of analysis.

$$_{n}L_{x} = n \cdot {}_{n}l_{x+n} + {}_{n}a_{x} \cdot {}_{n}d_{x} \tag{6}$$

The total useful life at the start of an interval ($_{n}T_{x}$) is defined in Eq. (7). It considers the stock in age interval plus the total useful life of the previous interval. The first interval (from 0 to n) considers the total summation of the total stock in the age interval. It indicates the total service years of all buildings.

$$_{n}T_{x} = {}_{n}T_{x+n} \cdot {}_{n}L_{x} \tag{7}$$

The average service life at the start of an interval ($_{n}e_{x}$) is defined in Eq. (8). It considers the total useful life at the start of the interval with the stock in the age interval. It indicates the life expectancy of a building in years, considering the year of construction at the start of the interval (x).

$$_{n}e_{x} = \frac{_{n}T_{x}}{_{n}l_{x}} \tag{8}$$

Note that the results of the life table give the probability of a building to reach the estimated age for the interval, based on the experience of the previous demolitions. That means that the buildings constructed in the year of analysis are estimated to reach an average age, but this does not mean that a building is not able to have a longer or shorter effective life.

3.2 Data acquisition

Since the state of the building is determining the moment of a building to reach the obsolescence period, the service life end is reached at the moment when a building gets the ruinous state. The buildings that are in ruinous state of conservation have a high risk of being demolished if no restoration or renovation takes place. In this state, the building cannot supply its requirements of habitability, and according to the definition of service life of a building (ISO 2011), it has reached the end of its service life. The fully renovated buildings are statistically considered to be re-birthing, so they are accounted as new living individuals.

The sources of data required to estimate the buildings service life are available, in the case of Spain, at the National Institute of Statistics (INE, Instituto Nacional de Estadística). Eurostat, the European Statistics from the European

Table 2 Life table of residential buildings in Spain, 2001

Age interval (year)	Range (year)	Demolitions	Buildings	Average of range (year)	Age-specific loss rate	Probability of loss	Probability of survive	Surviving stock at start of interval	Stock losses over interval	Stock in age interval	Total useful life at start of interval	Average service life at start of interval (year)
x	n	D_x	P_x	$_{n}a_{x}$	$_{n}M_{x}$	$_{n}q_{x}$	$_{n}P_{x}$	l_x	$_{n}d_{x}$	$_{n}l_{x}$	$_{n}T_{x}$	$_{n}e_{x}$
0–10	11	772	1,416,430	5.5	0.001	0.006	0.994	100,000	598	997,310	7,979,915	80
11–20	10	4,026	1,356,165	5	0.003	0.029	0.971	99,402	2,908	979,484	6,982,605	70
21–30	10	7,245	1,497,739	5	0.005	0.047	0.953	96,494	4,557	942,158	6,003,121	62
31–40	10	6,676	1,083,643	5	0.006	0.060	0.940	91,937	5,495	891,897	5,060,964	55
41–50	10	9,008	877,536	5	0.010	0.098	0.902	86,442	8,440	822,222	4,169,067	48
51–60	10	8,723	530,702	5	0.016	0.152	0.848	78,002	11,847	1,382,332	3,346,845	43
61–80	20	10,566	486,473	10	0.022	0.357	0.643	66,155	23,609	1,087,003	1,964,513	30
81–100	20	12,679	414,193	10	0.031	0.469	0.531	42,546	19,943	651,483	877,510	21
>101	20	35,099	866,200	10	0.041	1.000	0.000	22,603	22,603	226,028	226,028	10

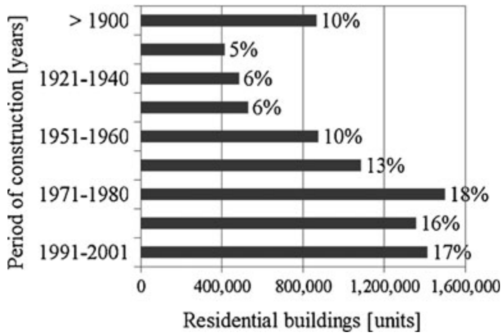


Fig. 1 Residential buildings (P_x) according to period of construction in Spain. (units: number of buildings). Source: INE (2007)

Commission, receives the data from INE. Eurostat and INE offer the "Census of dwellings" every 10 years, which gives information about the year of construction and the state of conservation of the residential building stock. In this paper, data about the last census of dwellings available have been used, which considers a period from 1900 to 2001 (INE 2007). The state of conservation is classified in four categories; (1) good, (2) defective, (3) bad, and (4) ruinous. The census does not present data about the number of demolished buildings (D_x), which is an essential parameter to determine the effective service life of the buildings. In order to fulfill this gap, the service life (ruinous state of the building) instead of the effective service life (demolition of the building) is considered in the life table. Therefore, the category *(4) ruinous* is taken as the death values (D_x). The surviving buildings correspond to the addition of the rest of categories: good, defective, and bad state. Based on that, the surviving buildings (P_x) and the deaths (D_x) for the considered years of study are presented in Table 1.

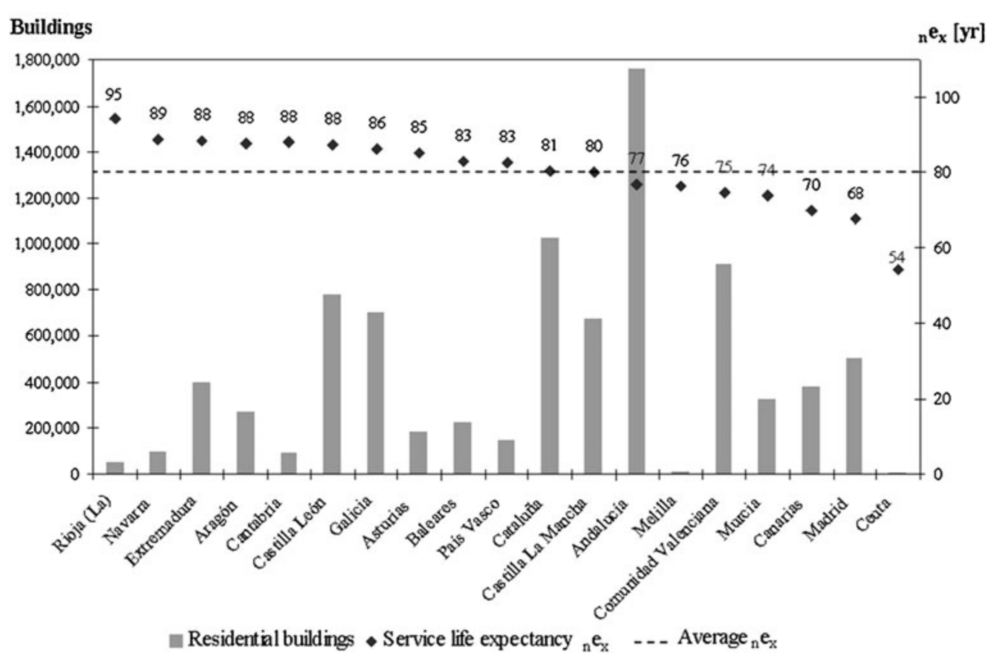
4 Life table results

The life table results of the dwelling stock in Spain are presented in Table 2. The results are referenced to year 2001. The average service life ($_ne_x$) at the start of the interval 0–10 showed that the life expectancy of a residential building in Spain constructed between 1991 and 2001 was 80 years. Most of the Spanish regions had a building life expectancy over the average. The highest life expectancy was found in La Rioja, with 95 years, and the lowest in Ceuta, with 54 years. According to average service life at the start of interval results, the older was the building, the shorter service life was expected.

Figure 1 shows the composition of the dwelling stock in Spain, considering the number of residential buildings (P_x) per period of construction. Half of the total dwelling stock was built within 1971 and 2001. These buildings were expected to have a service life from 62 to 80 years. Ten percent of the dwelling stock was over 101 years old and these dwellings were expected to reach the end of their lifespan within 10 years.

The service life expectancy of the dwelling stock and the number of buildings in the stock per region are presented together in Fig. 2. Big differences in the average service life among regions were found. The average service life of 12 regions was above the Spanish average, about 88 years. The largest dwelling stock was found in Andalucia (21 %) with an average service life of 77 years. Comunitat Valenciana had 11 % of the total stock with an average service life also under the average, 75 years. The large number of dwellings in Andalucia and Comunitat Valenciana made decreasing the Spanish average service life.

Fig. 2 Residential buildings in the stock and life expectancy of buildings in 2001, according to region. (units: number of buildings, $_ne_x$: in years)



5 Discussion

The life expectancy of the building stock in Spain is diverse. Every region has differences in the number of buildings constructed in each period and the life expectancy of the buildings according to the period of construction. The building stock suffers variations along the twentieth century due to historical and economical changes that meant changes in the building regulations along time and introduced variations in the constructive characteristics and composition of the materials of the building stock.

The building stock in Spain was relatively new; 50 % of total buildings are younger than 30 years old. That means that half of the building stock existing in 2001 (4,270,238 residential buildings) is expected to be in ruinous state during the period 2063 to 2081, according to the life table. The buildings constructed between 1941 and 1970 (2,491,881 residential buildings) are expected to be in ruinous state within the period 2044 to 2063, the ones constructed between 1900 and 1940 (900,666 residential buildings) from 22 and 2044, and the ones constructed before 1900 (866,200 residential buildings) are expected to be in ruinous state starting from 2011.

Their service life could reach the end if no full renovation or restoration takes place. Good maintenance of those buildings, which implies periodic renovation and restoration, allows prolonging their good state. Therefore, the estimation of the life expectancy presented by the life tables gives a guidance vision of the worst scenario, where no restoration and renovation activity take place in the building stock.

The life table of the building stock offers valuable information about the life expectancy of the current residential buildings. It can be used in LCA and furthermore allows considering in advance, from the early design phase of the building, the time of deconstruction, recycling, and further waste management. Service life can be used in the decision of future policies related to the renovation and restoration of buildings, the industry supplying the construction activity, urban planning, and territory planning.

6 Conclusions

This paper verifies that the life table can be applied to the accurate estimation of the building service life over building stocks and shows the development of the methodology and the keys in the data acquisition. Its quantification is based on the buildings census, given by official institutions, such as Eurostat in Europe or INE in Spain. Buildings census has to consider the year of construction and the state of conservation of the building to be applied in buildings' life table. The ruinous state is considered the end of the buildings' service life.

The life table has been applied to a case study of the dwelling stock in Spain, with data for the year 2001, when the last census of buildings was done by the National Institute of Statistics. Results over the case study show that the average life expectancy of a Spanish dwelling is 80 years.

The significant differences among the service life of buildings' Spanish regions show the importance of not estimating a rough service life that could lead to errors and how necessary is to calculate this parameter according to the inherent characteristics of the buildings in the region. The building stock in Spain was relatively new. Fifty percent of total dwellings were under 30 years old and, according to life table results, they are expected to be in ruinous state during the period 2063 to 2081.

Life table applied to buildings is not only useful to estimate the building service life, but also to predict the amount of buildings that will be in ruinous state in the next decades and therefore to know in advance the amount of buildings that will have to be refurbished.

In conclusion, the building service life is a useful parameter in diverse disciplines related to the building stock and its materials. The results of building service life from life tables can be applied by stakeholders in life cycle assessment, renovation and deconstruction of buildings in medium and long term, and future construction and demolition debris management.

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